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TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

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First Named Inventor	Zhihong WANG et al.
Art Unit	2834
Examiner Name	Thomas M. DOUGHERTY
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ENCLOSURES (check all that apply)

- ☐ Fee Transmittal Form
  - ☐ Fee Attached
- ☐ Amendment / Reply
  - ☐ After Final
  - ☐ Affidavits/declaration(s)
- ☐ Extension of Time Request
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- ☐ Information Disclosure Statement
- ☐ Certified Copy of Priority Document(s)
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1. Request for Certificate of Correction
2. Certificate of Correction
3. Copy of Corrected Patent
4. Postcard

Remarks

Certificate
JUL 1 1 2005
of Correction

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm	Kenyon & Kenyon		
Signature	Stephen T. Neal		
Printed Name	Stephen T. Neal		
Date	June 29, 2005	Reg. No.	47,815

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Signature	Barbara Vance	Date	June 29, 2005
Typed or printed name	Barbara Vance		

OIPE JUL 0 5 2005 JC83 PATENT & TRADEMARK OFFICE

Patent

Attorney Docket No.: 12553/106

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANTS	:	Zhihong WANG et al.
SERIAL NO.	:	10/632,638
FILED	:	August 1, 2003
PATENT NO.	:	6,856,070 B2
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FOR	:	DUAL STAGE ACTUATOR SYSTEMS FOR HIGH DENSITY HARD DISK DRIVES USING ANNULAR ROTARY PIEZOELECTRIC ACTUATORS
GROUP ART UNIT	:	2834
EXAMINER	:	Thomas M. DOUGHERTY

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Date: June 29, 2005 Signature Barbara Vance

Barbara Vance

REQUEST FOR CERTIFICATE OF CORRECTION

Dear Sir:

We have compared the above patent with the application as filed and have found errors in the printing of the patent. We respectfully request that the enclosed Certificate of Correction on Form PTO-1050 be issued correcting the mistakes set forth therein under authority of 35 U.S.C. §254. The exact column and line number where the errors occurred in the patent are listed on the enclosed certificate.

The errors that appear in the patent are various typographical errors made by both the Applicant and the Patent Office and no fee is believed required.

The Office is hereby authorized to charge any additional fees, or credit any overpayments, to Deposit Account No. **11-0600**.

Respectfully submitted,

KENYON & KENYON

Dated: June 29, 2005

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO : 6,856,070 B2

DATED : February 15, 2005

INVENTOR(S) : Zhihong WANG et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Section (75) Line 3 "Masashi Shiraishi, Dongguang (CN);"
should be --Masashi Shiraishi, Dongguan (CN);--

Section (75) Line 4 "Ping Shang, Dongguang (CN);"
should be --Ping Shang, Dongguan (CN);--

Section (75) Line 5 "Wu, Dongguang (CN);"
should be --Wu, Dongguan (CN)--

Column 1, Line 28 "maganic"
should be --magnetic--

Column 2, Line 4 "gimble"
should be --gimbal--

Column 3, Line 65 "ilustrated"
should be --illustrated--

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(54) DUAL STAGE ACTUATOR SYSTEMS FOR HIGH DENSITY HARD DISK DRIVES USING ANNULAR ROTARY PIEZOELECTRIC ACTUATORS

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/632,638**

(22) Filed: **Aug. 1, 2003**

(65) **Prior Publication Data**

US 2004/0021404 A1 Feb. 5, 2004

Related U.S. Application Data

(62) Division of application No. 09/811,112, filed on Mar. 16, 2001, now Pat. No. 6,653,763.

(30) **Foreign Application Priority Data**

Jun. 8, 2000 (WO) PCT/CN00/00148

(51) **Int. Cl.**^{7} **H01L 41/09**

(52) **U.S. Cl.** **310/317**; 310/359; 310/367; 310/369

(58) **Field of Search** 310/366–370, 310/317, 359, 26; 360/292, 294.4, 294.6

(56) **References Cited**

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* cited by examiner

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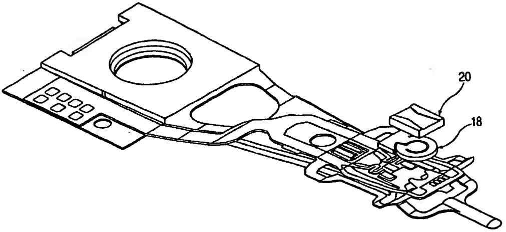
(74) *Attorney, Agent, or Firm*—Kenyon & Kenyon

(57) **ABSTRACT**

A piezoelectric actuator is disclosed including an annular piezoelectric element and a base. There is a gap along the radial direction of the annular piezoelectric element. One of the two ends, i.e., the fixed end of the said annular element, is connected to the base, while the other end is free. The base is made of piezoelectric materials. Furthermore, the annular element is divided into two or more annular parts along the direction of its circumference by the electrode patterns applied on its two opposite surface and/or its polarization directions. When driving voltages are applied, the actuator can generate roughly a rotary motion around the center of the annular piezoelectric element. The annular rotary actuator could be either a single plate or with multilayer structure. The present invention further relates to a dual stage head positioning actuator system of a hard disk drive with a plurality of disks and a plurality of vertically aligned head sliders mounted on distal ends of a plurality of suspensions via the annular piezoelectric actuators.

8 Claims, 10 Drawing Sheets



DUAL STAGE ACTUATOR SYSTEMS FOR HIGH DENSITY HARD DISK DRIVES USING ANNULAR ROTARY PIEZOELECTRIC ACTUATORS

This application is a Divisional of patent application Ser. No. 09/811,112, filed on Mar. 16, 2001 now U.S. Pat. No. 6,653,763.

FIELD OF THE INVENTION

The present invention generally relates to the field of piezoelectric devices and more particularly, but not by way of limitation, to an annular rotary piezoelectric actuator suitable for use as a secondary fine actuator in a dual stage head positioning servo system of a hard disk drive and to a dual stage actuator system for a high density hard disk drive using the annular rotary piezoelectric actuator.

DESCRIPTION OF THE RELATED ART

Piezoelectric actuators have been used as positioners or driving motors in a broad spectrum of fields such as optics, precision machining, fluid control and optical disk drives due to their characteristics of small size, simple structure, quick response and, most importantly, controllable displacement down to nanometers.

In the area of hard disk drives, however, there exists a competition between micro machining electrostatic, electro- agnetic ~~maganic~~ micro actuators and piezoelectric actuators. The micro machining actuators are designed to drive the slider directly. An advantage of this type of actuator is its higher resonance frequency, but its stroke/voltage sensitivity is very small. The piezoelectric actuators, on the other hand, are commonly used to control the motion of the suspension. Compared with the former, the latter has a larger stroke/voltage sensitivity and a relatively lower resonance frequency. Unfortunately, the resonance frequency and stroke are of the same importance to the dual stage head positioning servo system of the hard disk drive. A piezoelectric actuator is disclosed in U.S. patent application Ser. No. 08/874,814 (U.S. Pat. No. 5,898,544) filed on Jun. 13, 1997 by Todd A. Krinke et al. entitled Base Plate-mounted Microactuator for a Suspension which is assigned to Hutchinson Technology Incorporated.

Regarding the piezoelectric actuator, for the purpose of decreasing the driving voltage, d_{31} type multilayer, split-morph multilayer and Π-beam multilayer are presented as the secondary fine actuators of the dual stage servo system. However, the conflict of resonance frequency and stroke still remains unresolved.

In the present invention a micro machining piezoelectric actuator used to drive the slider directly is proposed to meet the requirements of resonance frequency and stroke simultaneously.

SUMMARY OF THE INVENTION

A general object of the present invention is to provide a new structure of piezoelectric actuator which has a function of generating rotary deformation around its shape center.

A specific object of the present invention is to provide a piezoelectric actuator which can be used as a secondary actuator in a dual stage servo system of a hard disk drive.

A more specific object of the present invention is to provide a piezoelectric actuator which can be mounted between the suspension and the slider to drive the magnetic pole tip of the slider to move across data tracks so as to obtain a head positioning servo system with high bandwidth.

Yet another specific object of the present invention is to provide a piezoelectric actuator which has a symmetric configuration and a simple potting process so that it can be easily manufactured and realized in a head ~~gimble~~ assembly gimbal (HGA).

Another object of the present invention is to provide a piezoelectric actuator which has enough displacement stroke to meet the requirement of compensating tracking misregistration under a supply voltage up to 15 volts.

The above objects can be achieved according to embodiments of the present invention by designing the configuration, selecting appropriate electrode patterns and corresponding poling scheme of a piezoelectric element. Hereinafter the typical practice means will be described.

In accordance with one aspect of the present invention, an annular piezoelectric element with a gap along the radial direction is divided into two parts by an electrode crevice along its circumference at a certain radius. Polarization vectors in these parts are generally in the direction of its thickness and can be polarized either in the same or opposite direction. One of the two ends of the element is affixed to a base. Driving voltages are so arranged that they make one of the two parts expanded by the '31' action while the other contracted, or one of the two parts expanded or contracted while the other remains constant. This will result in roughly a rotary motion of the free end around its center, rather like the bending of a split-morph actuator, where the bending is in the direction of its width. This actuator is actually an annular split electrode rotary piezoelectric actuator. Analogous to the name of "split-morph", it can be defined as "annular split-morph". If only one of the two parts is polarized, this actuator can be called partial poling annular split-morph. If the poling vectors in the two corresponding parts of the element are opposite to each other, this actuator is called antiparallel annular split-morph, and if the poling vectors are the same, it is called parallel annular split-morph

In accordance with another aspect of the present invention, a dual stage head positioning actuator system is provided for a hard disk drive having a plurality of disks and a plurality of vertically aligned head sliders mounted on distal ends of a plurality of suspensions via micro piezoelectric actuators. In one embodiment, the dual stage head positioning actuator system includes

- a voice coil motor as the primary stage actuator to simultaneously drive the plurality of suspensions in a long stroke; and
- a plurality of piezoelectric actuators as the secondary fine actuator to drive the head slider individually in a fine stroke for precisely positioning a slider to a predetermined position on a respective disk surface of the plurality of disks.

The actuator as described above is used as the fine actuator and each of the plurality of fine actuators is mounted on an associated flexure tongue of one of the plurality of suspensions through the base, and the slider is potted on the inner disc of the actuator.

In accordance with a further aspect of the present invention, a driving voltage scheme is provided for any two pieces of the piezoelectric elements or any two active parts in one piezoelectric element that enable the two pieces or two parts to expand and contract at the same time, respectively, while the direction of the driving voltages preserves the poling directions of the corresponding pieces or parts throughout the operation so as to prevent depoling of the piezoelectric element. The voltages applied on the electrodes of the two pieces or two parts are two opposing

phase AC signals added to a positive DC bias which has the same directions as the poling vector of the pieces or parts, the bias is larger than or at least equal to the amplitude of the AC signal.

Consequently, the driving voltages can precisely control the rotary angle of the free end of the suspension.

One important advantage and a novel aspect of the present invention involves the feature of the annular structure and the method of separating the annular structure into active parts and inactive parts which enable the actuator to have the function of generating rotary motion within the electrode plane. With these advantages and features, the actuator with dimensions similar to the slider can be installed between the suspension, more specifically, flexure tongue and slider to drive the magnetic pole tip of the slider wide and fast to follow a moderate runout.

Another important feature of the present invention is that the actuator can easily be fabricated into a multilayer structure with various dimensions by tape casting, thick film screen printing, sand blasting and techniques of MEMS (microelectro mechanical systems).

Other objects, as well as the structure and features of the present invention to achieve those objects, will be apparent by considering the following detailed description of preferred embodiments, presented in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top prospective view of the simplest structure of an annular split-morph.

FIG. **2** is a top prospective view of an annular split-morph with an inner disc.

FIG. **3** is a top prospective view of a multilayer annular split-morph with an inner disc.

FIG. **4** is a top plan view of the internal electrode patterns and their alignment.

FIGS. **5**A and **5**B are a top plan view and side view of an annular split morph with an inner disc and a rectangular surrounding base.

FIG. **6** is a front view of an S-type rotary actuator of the present invention.

FIG. **7** is a front view of a tri-beam rotary actuator of the present invention.

FIGS. **8**, **8**A and **8**B are a top plan view and side views of a piezoelectric actuator stage.

FIG. **9** illustrates a configuration of a typical assembly of an actuator of the present invention and a slider.

FIGS. **10**A, **10**B, and **10**C are diagrams showing relative positions between the rotary actuator and the slider.

FIG. **11** and FIG. **12** are side views of a suspension assembly with the micro piezoelectric actuator of the present invention.

FIG. **13** is an assembly view of an embodiment on HGA.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, basic structures and preferred embodiments of the present invention will be described with reference to the drawings. FIG. **1** through FIG. **5**B show the basic structures and the corresponding operations of the present invention.

Referring more particularly to FIG. **1**, the simplest structure of the present invention is ~~illustrated.~~ lustrated It is just a single piece of piezoelectric plate with an annular configuration thickness t and polarized in the direction of its thickness.

In FIG. **1**, designated by reference **1** is an annular piezoelectric plate with a gap **2** in a radial direction On the two opposite surface of the plate are the electrodes with definite patterns. The plate is furthermore divided into two, i.e., inner and outer parts I and O by the electrode patterns. **3** and **4** indicate two pairs of upper and lower electrodes of O and I. Further, **5** indicates an electrode crevice where no electrode is applied on piezoelectric plate **1**. Designated by reference numeral **6** is the joint of one end of the annular plate to the base. **7** indicates the other end, i.e., the free end of the annular plate. In this embodiment, the annular plate and the base are an integral body made of the same piezoelectric materials. As described hereinbefore, the two parts I and O can be poled either in the same or opposite direction to form a parallel annular split-morph or an antiparallel annular split-morph. It might also be so arranged that only I or O are poled to form the so-called partial poling split-morph. Shown in FIG. **1** is a parallel split-morph. Arrows shown in all the drawings hereinafter represent polarization directions.

As shown in FIG. **1**, the direction from the annular plate center to the middle point of the base edge is designated as the x-axis, the electrode plane as the x-y plane and the height direction as z-axis. The deformation of the free end as it moves under the effect of a driving voltage is then roughly a rotation around its center. Therefore, displacement of the free end along y-axis can be achieved. In this embodiment, the middle part of the annular element, designated by reference M, has also a slight displacement along the x-axis. The rotary angle, so as the displacement/voltage sensitivity, and resonance frequency of the actuators can be accurately controlled by varying the dimensions of its inner and outer radii, thickness t and electrode patterns. It should be noted that all the drawings refereed to in this document are not to scale.

FIG. **2** illustrates a modification of the simplest structure shown in FIG. **1**. In FIG. **2**, reference numerals the same as those in FIG. **1** designate the same components. The operation of this actuator is similar to the actuator shown in FIG. **1**. The only difference is that there is an inner disk **8** connected to the free end of the annular plate and it also constructs an integral body with the annular part. The inner disc can provide a relatively larger area on which the object to be driven, for example, the slider, is potted so that the disc can transmit the rotation of the free end to the object. The inner disc itself also roughly rotates around a center.

To obtain a large stroke and a high resonance frequency are basic requirements of micro actuator design, especially for the secondary stage actuator of a dual stage servo system. It is necessary to increase the rigidity in the height direction while maintaining relatively high displacement/voltage sensitivity of the actuator, i.e., getting a large generative displacement under a relatively lower driving voltage. In order to fulfill this purpose, a multilayer structure of the present invention is proposed and will be described below with reference to the drawings.

There are several different configurations of this multilayer annular split-morph due to differences in the selected manufacturing method. Taking the poling scheme into consideration, there is also the differentiation of parallel, antiparallel and partial poling multilayer actuators. Multilayer structures can be achieved simply by potting two or more single thin plate actuators together or manufactured by various traditional multilayer processes. Typical forms and variations of the present invention will be depicted below with reference to FIG. **3** through FIG. **5**.

FIG. **3** shows a typical configuration and its driving voltage scheme of a multilayer structure of the present